Seismic Response of 3-Span Bridges Considering the effect of Failure of Bearings

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1. INTRODUCTION

One of the major changes in design practice after the Kobe earthquake is the extensive use of elastomeric bearings which allow relative displacement to take place between the superstructure and substructures to mitigate the build up of seismic force. However increase of relative displacement between the superstructure and the substructure may cause the unseating, thus the restrainers are widely used to avoid the failure of the decks. Although the effect of bearings and restrainers has been considered in seismic response analysis of bridges, effect of failure considering the failure of bearing and it failure mechanism of those structural components has not yet been fully analyzed. This paper presents an analysis of progressive failure of elastomeric bearings and effect of seismic response with unseating prevention devices for a 3-span simply supported bridge.

2. TARGET STRUCTURE AND IDEALIZATION OF STRUCTURE

A 3-span simply supported steel I-girder bridge as shown in Fig. 1 was analyzed. The deck is consisted of a concrete slab and 5 steel girders (G1-G5). Each deck is 40-meter long and the gap between the decks is 100 mm. Decks with a weight of 6.53 MN each were supported by 8-16m tall T-shaped cantilevered piers. Decks are supported by elastomeric bearings at each girder and scale is 96 mm tall and 440 mm wide and long. They are designed assuming smaller lateral force demand required by design code so that they fail in analysis. PC cable restrainers are accommodated between Decks 2 and Decks 3, and Decks 3 and Decks 4.

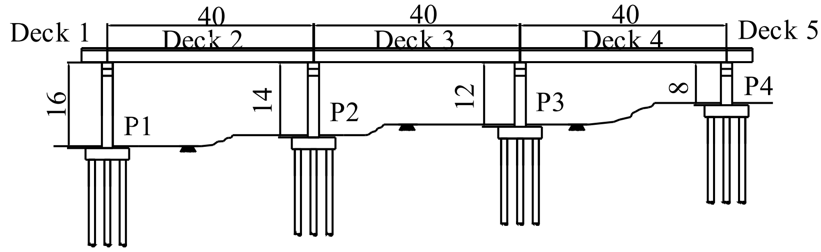

Fig. 1 Target bridge (unit in meter)

Poundings which occur between adjacent decks are idealized by impact springs as shown in Fig. 2 (a). It is assumed that the elastomeric bearings rupture when shear strain induced in rubber exceeds 250%. Rupture of elastomeric bearings is taken into analysis by using an analytical model as shown in Fig. 2 (b). The lateral force vs. lateral displacement hysteresis is linear until bearings rupture, however it becomes zero once the shear strain induced in rubber reaches 250%. The lock of an elastomeric bearing is idealized as shown in Fig. 2 (c). Gap when lock occurs from the rest position is assumed as 50 mm here. Hysteretic behavior of cable restrainers is idealized as shown in Fig. 2 (d).Tension and deformation capacities of PC cable restrainers are set 0.574 MN and 16.5 mm, respectively. The tension capacity is about a half of the code demand, but the restrainers did not rupture as will be presented later. It consists of a PC strand with a diameter of 26 mm. The movable gap of the restrainers is assumed as 50mm.

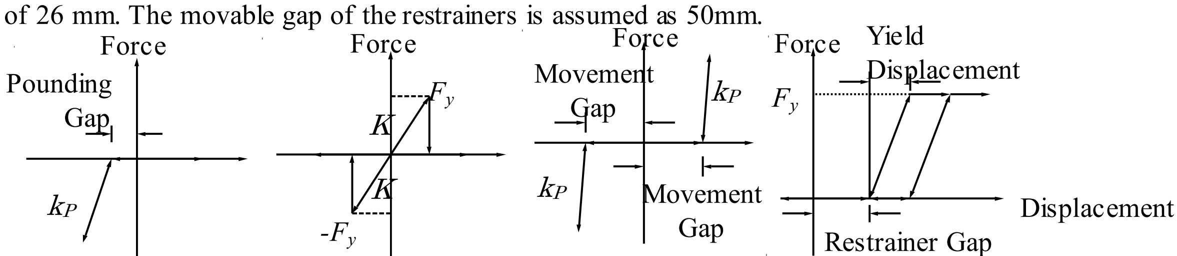

Fig. 2 Idealization of pounding, bearing and cable restrainer

3. SEISMIC RESPONSE OF THE BRIDGE WITHOUT RESTRAINERS

Fig. 4 **(a)** shows deck response in the longitudinal direction. Because all elastomeric bearings failed, the displacement of Decks 2 and 3 become subsequently excessively large. Permanent displacement reached nearly 0.88 m and 0.57 m at the Deck 2 and 3, respectively. As shown in Fig. 3, bearings on P2 failed at 4.36-4.37 second. It is interesting to note here that among five bearings on P2 the bearing supporting G1 girder (which is designated hereinafter as G1 bearing) of Deck 3 failed first at 4.362 sec. and G2, G3, G4 bearings successively failed and finally G5 bearing failed at 4.37 sec.

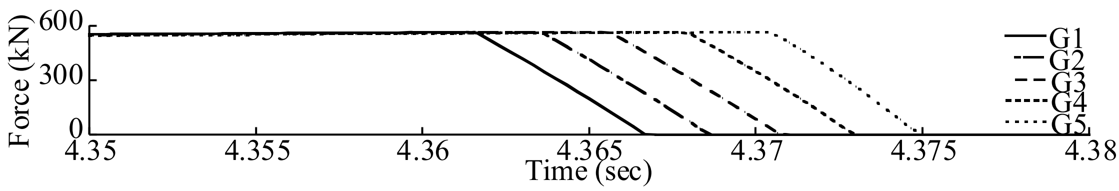

Fig. 3 Progressive failure of bearings which support Deck 3 on Pier 2

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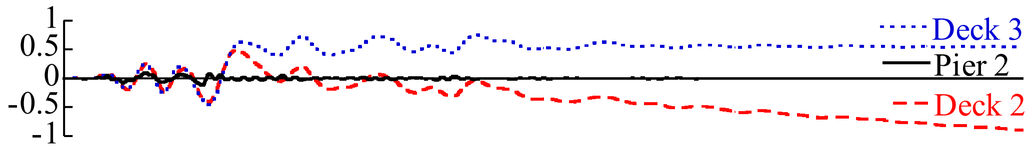
4. EFFECT OF CABLE RESTRAINERS

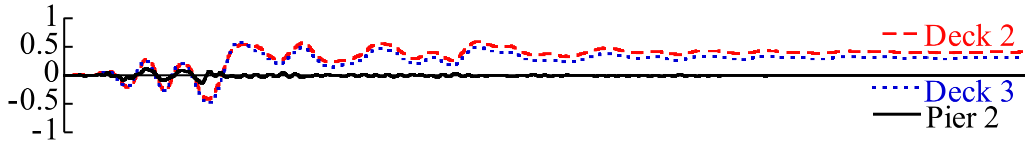
Fig. 4(b) shows the deck response when PC cable restrainers are accommodated. Because elastomeric bearings failed at 5.272-5.28 sec, permanent displacement of Decks 2 and 3 reached about 0.5 m. However the deck displacements of Decks 2 and 3 are smaller than those when restrainers are not accommodated (refer to Fig. 4 **(a)**).

5. EFFECT OF "LOCK" OF A BEARING AFTER FAILURE

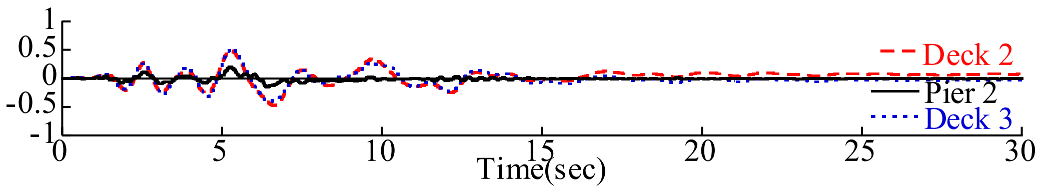
It is assumed here that G1 bearing of Deck 3 on P2 failed and locked. Fig. 4(c) shows the deck response when all bearings fail and only this bearing locks. Because Decks 2 and 3 are tied together by restrainers, they responded in a similar manner. Because the lock at G1 bearing prevented excessive movement of the Deck 3 on P2, deck response displacements are smaller than those when lock of bearing does not occur (refer to Fig. 4(b)). However, a large lateral force of 24.7 MN was induced at G1 bearing of Deck 3 on P2, which is 3.7 times the deck weight. This resulted in larger inelastic behavior in P2 as show in Fig. 5 (b). Response ductility was nearly 5. It is interesting to note that the lock of a failed bearing can result in unanticipated damage in other main structural components.



(a) Without cable restrainer

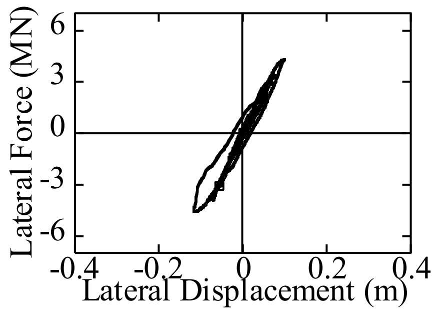


(b) With cable restrainer

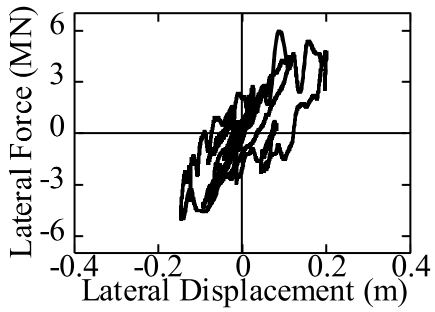


(c) With cable restrainer and a lock of a bearing

Fig. 4 Comparison of response displacement of the Deck2, Deck3 and Pier2



(a) Without Lock



(b) With Lock

Fig. 5 Lateral force vs. lateral displacement hystereses of Pier 2 when cable restrainer are not accommodated

6. CONCLUSIONS

・Elastomeric bearings fail progressively from the edges due to rotations of the decks under bilateral ground motions. Similarly cable restrainers yield from the edges. Design concept to evaluate demands of the bearings and unseating prevention devices by dividing the total demand by number of devices underestimates the real demands at edges.

・"Lock" of bearings results in concentration of lateral force which is transferred from the deck to the substructures and adjacent decks by restrainers. Because it is difficult to predict the locations where lock occurs, worst scenario has to be clarified based on engineering experience and analysis.